The Progress of the Copernican Astronomy Among English Scientists to 1645 and its Reflection in Literature from Spenser to Milton

A DISSERTATION

Submitted to the Board of University Studies of The Johns Hopkins University in Conformity with the Requirements for the Degree of Doctor of Philosophy

1935

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FRANCIS R. JOHNSON

BALTIMORE

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CONTENTS OF COMPLETE DISSERTATION

CHAPTER

I. Introduction: The Sources and Scope of this Study of Scientific Thought

II. The Pre-Copernican Conceptions of the Universe

III. Copernicus and the Heliocentric System

IV. Astronomical Scholarship in England and the Copernican Theory to 1575

V. The Progress of the Copernican Astronomy from Thomas Digges to William Gilbert, 1576-1600

VI. The Changes in Astronomical Thought Between 1600 and 1645

VII. The New Astronomy and English Literature

Bibliography

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INTRODUCTION

The purpose of this dissertation is to study the English writings on science from about 1500 to 1645 in order, first, to determine the attitude of the leading writers on astronomy toward the rival claims of the new and the old systems, and second, to discover how far the scientific point of view is reflected in the works of some of the most noted authors of the time. By tracing, from the scientific point of view, the gradual stages in the overthrow of the ancient Aristotelio-Ptolemaic cosmology by the discoveries of Copernicus, Tycho Brahe, Gilbert, Kepler, and Galileo, it seeks to re-create a certain portion of the intellectual background of the Renaissance.

After a brief survey, in Chapter I, of the obstacles to our understanding of the astronomical ideas of the sixteenth century and of the significance of the vernacular works in the popular dissemination of astronomical knowledge, this study proceeds in Chapter II to detail the historical development of the conception of the structure of the universe which prevailed before the publication of the *De revolutionibus* in 1543. Chapter III analyzes the scientific and philosophic impact of the Copernican theory and its intrinsic relationship to the older system based upon Aristotle and Ptolemy. The next three chapters chart the course of astronomical thought as revealed in the writings of English scientists during the century following Copernicus, with incidental references to important literary men and the extent to which they kept abreast of the current of scientific thought in their time. In the final chapter the writings of several outstanding figures in English literature are examined in order to note the precise manner in which they reflect the progress of the new astronomy with its gradual shift from the Aristotelio-Ptolemaic system to the systems of Tycho Brahe and Copernicus or to combinations of the two latter schemes of the universe.

This study of the discussions of astronomy in English books reveals that there was a steady progress of the new ideas—a progress which at every step was closely bound up with that gradual increase in astronomical knowledge which was disproving the old doctrines and providing scientific data to lend greater credit to the newer theories.

The following pages contain an extract from the opening section of Chapter V of the dissertation, as printed, with some revisions, in Chapter VI of *Astronomical Thought in Renaissance England* (Baltimore, 1937).

Chapter VI

THOMAS DIGGES AND THE PROGRESS OF THE COPERNICAN ASTRONOMY

In his book on the new star, the *Alae,* Thomas Digges had not only won for himself a place beside John Dee as one of the two most eminent astronomers and mathematicians in England; he had also done great service to English science by his insistence on the experimental method. At the same time, he had become the recognized leader of the English supporters of the Copernican theory, and no one in Europe had shown greater eagerness to put the new heliocentric system to the test of observations and experiments which should either confirm it or necessitate some further modifications in Copernicus' hypothesis. The *Alae,* however, had been written in Latin for an international audience. Digges's next work was designed to make a knowledge of the essential features of the new system of the universe available to his less learned countrymen, and particularly to the skilled artisans and mechanics whose intelligent co-operation was so necessary to successful research in the sciences.

When, in 1576, the printer, Thomas Marshe, prepared to issue a new edition of Leonard Digges's *Prognostication euerlasting,* Thomas Digges took advantage of this opportunity to revise his father's work and to make some important additions. The most significant of these was a supplement describing the Copernican universe, entitled *A Perfit Description of the Caelestiall Orbes according to the most aunciente doctrine of the Pythagoreans, latelye reuiued by Copernicus and by Geometricall Demonstrations approued.* Besides a diagram of the heliocentric system, it gave an English translation of the principal sections of Book I of the *De revolutionibus,* in which the author had set forth the essential features of his new system and the chief arguments in its favor.

Digges clearly states, in his preface to the reader, the reasons

which prompted him to make this addition to his father's book.[1] He was unwilling to allow the description of the universe according to the Ptolemaic theory to go unchallenged, since the new system of Copernicus was so much more logical and mathematically harmonious. He therefore "thought it conuenient together with the olde Theorick also to publish this, to the ende such noble English minds (as delight to reache aboue the baser sort of men) might not be altogether defrauded of so noble a part of Philosophy."

The preface to Thomas Digges's treatise on the Copernican theory also makes clear that the author was in no way deceived by the common assertion, based on Osiander's spurious preface to the *De revolutionibus,* that Copernicus had put forward his hypothesis merely to simplify mathematical calculations and had not himself believed it to be physically true. Digges says:

> And to the ende it might manifestly appeare that *Copernicus* mente not as some haue fondly excused him to deliuer these grounds of the Earthes mobility onely as Mathematicall principles, fayned & not as Philosophicall truly auerred. I haue also from him deliuered both the Philosophicall reasons by *Aristotle* and others produced to maintaine the Earthes stability, and also their solutions and insufficiency, wherein I cannot a litle commende the modestie of that graue Philosopher *Aristotle,* who seing (no doubt) the insufficiency of his owne reasons in seeking to confute the Earthes motion, vseth these words. *De his explicatum est ea qua potuimus facultate* howbeit his disciples haue not with like sobriety maintayned the same.[2]

The attitude toward Aristotle which Digges expresses in this passage is the one which we have already noted as typical of the ablest English scientists of the period. It is interesting, moreover, that, in his attack upon the Aristotelians who rigidly maintained their master's infallibility in scientific matters, he quotes from the well-known work of Palingenius.[3] Digges's

[1] *A Prognostication euerlastinge of righte good effecte . . . Published by Leonard Digges Gentleman. Lately corrected and augmented by Thomas Digges his sonne* (London: Thomas Marsh, 1576), sig. M1[r]. Digges's supplement on the Copernican system is reprinted in Johnson and Larkey, "Thomas Digges, the Copernican System, and the Idea of the Infinity of the Universe in 1576."

[2] *A Perfit Description of the Caelestiall Orbes,* sigs. M1[r]-M1[v].

[3] Cf. *supra,* p. 147; Digges quotes part of this same passage.

familiarity with the *Zodiacus vitae* was commented upon by Gabriel Harvey, who tells us that " M. Digges hath the whole Aquarius of Palingenius bie hart: & takes mutch delight to repeate it often." [4] This knowledge is quite evident throughout the preface to Digges's work. He makes a special point of Palingenius' allusion to the early ideas of Anaxagoras and Democritus that every star was a world,[5] and reprints the poet's lines in the following form:

> Singula nonnulli credunt quoque sydera posse
> Dici Orbes, TERRAMque appellant sydus opacũ
> Cui minimus Diuûm praesit &c.

The word " Terram " is printed in extremely large capitals, with the obvious design of calling attention to some of the startling implications of the new theory by means of the adroit use of a quotation from an author known and admired by nearly all of Digges's fellow countrymen.

In translating the principal chapters of the first book of Copernicus' great work, Digges followed the usual Elizabethan practice of working phrase by phrase, rather than word by word, so that the general result is an excellent piece of Elizabethan prose, which, although not an absolutely literal translation, is consistently faithful to Copernicus' meaning.[6] When Digges varies from Copernicus, it is usually on the side of giving greater emphasis to the implied criticisms of some current cosmological ideas.[7] He also adds further evidence to support

[4] G. C. Moore Smith, *Gabriel Harvey's Marginalia,* p. 161.

[5] Cf. *supra,* p. 147.

[6] The only other English translation of comparable portions of the *De revolutionibus* is that published in Shapley and Howarth, *A Source Book in Astronomy.* So far as prose style is concerned, I believe that almost any reader will agree that the Elizabethan translation by Digges is far superior to the modern one. Compare the passages from the two translations, quoted *supra,* pp. 97-101.

[7] For example, in speaking (sig. N1^{v}) of the space between the earth and the moon, in which we know " nothinge but the aire, or fiery Orbe if any sutch be," Digges makes more emphatic the doubt cast upon the existence of the sphere of fire, just below the moon. Copernicus' words were (*De revolutionibus,* fol. 6^{r}) " nihil tamen aliud in tanto spacio nouimus contineri quàm aërem. & si placet etiam, quod igneum vocant elementum."

Copernicus' refutation of the Aristotelian contention that, if the earth rotated, objects dropped from a high tower would be left behind and finally hit the ground a considerable distance to the west of the tower. Digges brings forward the very pertinent experiment, which he had probably made himself, of dropping an object from the mast of a moving ship and noting that it appeared to fall to the deck in a straight line parallel to the mast. He says:

> And of thinges ascēdinge and descendinge in respect of the worlde we must confesse them to haue a mixt motion of right & circulare, albeit it seeme to vs right & streight, No otherwise then if in a shippe vnder sayle a man should softly let a plūmet downe from the toppe alonge by the maste euen to the decke: This plummet passing alwayes by the streight maste, seemeth also too fall in a righte line, but beinge by discours of reason wayed his Motion is found mixt of right and circulare.[8]

By far the most important addition which Digges made to Copernicus, however, was his assertion that the heliocentric universe should be conceived as infinite, with the fixed stars located at varying distances throughout infinite space. Copernicus, as previously noted,[9] although bringing the question of the infinity of the universe into his refutation of his Aristotelian opponents, had refused to commit himself on this subject. Instead, he had retained in his diagram of the universe the finite sphere of fixed stars, merely making this sphere sufficiently large to account for the absence of any perceptible stellar parallax. Digges, however, clearly perceived that, the moment the rotation of the earth was conceded, there was no longer any necessity for picturing the stars as attached to a huge, rotating sphere at a definite distance from the earth. At the same time, Aristotle's oft-quoted mathematical proofs of the finiteness of the universe were automatically invalidated.[10] Therefore, Digges had the courage to break completely with the older cosmologies by shattering the finite outer wall of the universe. He was the first modern astronomer of note to portray an

[8] Sig. O2r. [9] Pp. 106-7. [10] Cf. *supra*, pp. 40-44.

infinite, heliocentric universe, with the stars scattered at varying distances throughout infinite space.

Digges's diagram of the universe, printed in the 1576 and in all later editions of the *Prognostication euerlasting,* was the representation of the new Copernican system most familiar to the average Englishman of the Renaissance.[11] It followed the plan printed in the *De revolutionibus* so far as the planets were concerned, but, instead of representing the sphere of the fixed stars by merely the customary circle standing for the eighth sphere, it scattered the stars out to the borders of the diagram, and inserted the legend: "This orbe of starres fixed infinitely vp extendeth hit self in altitude sphericallye, and therfore immouable; the pallace of foelicitye garnished with perpetuall shininge glorious lightes innumerable, farr excellinge our sonne both in quantitye and qualitye . . ."

In the text of his translation of Copernicus, Digges inserted the following paragraph of his own, emphasizing the same idea:

Heerein can wee neuer sufficiently admire thys wonderfull & incomprehensible huge frame of goddes woorke proponed to our senses, seinge fyrst thys baull of y^e^ earth wherein we moue, to the common sorte seemeth greate, and yet in respecte of the Moones Orbe is very small, but compared with *Orbis magnus* wherein it is caried, it scarcely retayneth any sensible proportion, so merueilously is that Orbe of Annuall motion greater than this litle darcke starre wherein we liue. But that *Orbus magnus* beinge as is before declared but as a poynct in respect of the immēsity of that immoueable heauen, we may easily consider what litle portion of gods frame, our Elementare corruptible worlde is, but neuer sufficiently be able to admire the immensity of the Rest. Especially of that fixed Orbe garnished with lightes innumerable and reachinge vp in *Sphaericall altitude* without ende. Of whiche lightes Celestiall it is to bee thoughte that we onely behoulde sutch as are in the inferioure partes of the same Orbe, and as they are hygher, so seeme they of lesse and lesser quantity, euen tyll our sighte beinge not able farder to reache or conceyue, the greatest part rest by reason of their wonderfull distance inuisible vnto vs. And this may wel be thought of vs to be the gloriouse court of y^e^ great god, whose vnsercheable worcks inuisible we may partly by these his visible cōiecture, to whose infinit power and maiesty such an infinit place surmountinge all other both in quantity and quality only is conueniente. But because

[11] See Fig. II.

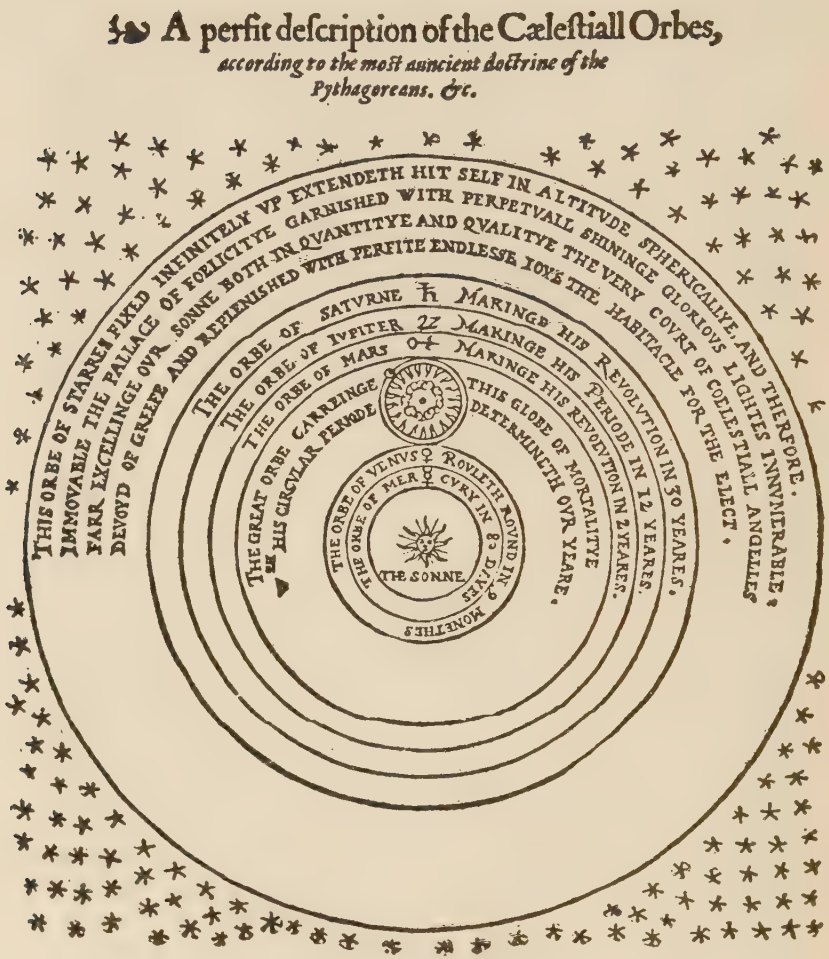
A perfit deſcription of the Cæleſtiall Orbes,
according to the moſt auncient doctrine of the Pythagoreans, &c.
THIS ORBE OF STARRES FIXED INFINITELY VP EXTENDETH HIT SELF IN ALTITVDE SPHERICALLYE, AND THEREFORE IMMOVABLE THE PALLACE OF FORLICITYE GARNISHED WITH PERPETVALL SHININGE GLORIOVS LIGHTES INNVMERABLE, FARR EXCELLINGE OVR SONNE BOTH IN QVANTITYE AND QVALITYE THE VERY COVRT OF COLLESTIALL ANGELLES DEVOYD OF GREEFE AND REPLENISHED WITH PERFITE ENDLESSE IOYES THE HABITACLE FOR THE ELECT.
THE ORBE OF SATVRNE ♄ MAKINGE HIS REVOLVTION IN 30 YEARES.
THE ORBE OF IVPITER ♃ MAKINGE HIS PERIODE IN 12 YEARES.
THE ORBE OF MARS ♂ MAKINGE HIS REVOLVTION IN 2 YEARES.
THE GREAT ORBE CARRINGE ☿ ♀ ☉ ☽ THIS GLOBE OF MORTALITYE HIS CIRCVLAR PERIODE DETERMINETH OVR YEARE.
THE ORBE OF VENVS ♀ ROVLETH ABOVND IN 8 DAYES
THE ORBE OF MERCVRY ☿ IN 23 DAYES
THE SONNE
MONETHES

FIG. II.—THOMAS DIGGES'S DIAGRAM OF THE INFINITE COPERNICAN UNIVERSE

From *A Perfit Description of the Caelestiall Orbes* (1576)

the world hath so longe a tyme bin carryed with an opinion of the earths stabilitye, as the contrary cannot but be nowe very imperswasible, I haue thought good out of *Copernicus* also to geue a taste of the reasons philosophicall alledged for the earthes stabilitye, and their solutions, that sutch as are not able with *Geometricall* eyes to beehoulde the secrete perfection of *Copernicus Theoricke,* maye yet by these familiar, naturall reasons be induced to serche farther, and not rashly to condempne for phantasticall, so auncient doctrine reuiued, and by *Copernicus* so demonstratiuely approued.[12]

It is worth noting that Digges fully realized the huge size of the stars which followed as a mathematical consequence of the Copernican hypothesis, for his legend asserts that these stars far excel the sun both in quantity and quality.[13] Furthermore, in the paragraph he added to Copernicus, he made a point of the fact that the essential merits of the new system could be fully appreciated only by the mathematicians, yet proceeded to give, out of Copernicus, the refutations of the usual arguments of the Aristotelians against the new system, even inserting, as we have observed, some additional evidence of his own against the current physical theories.

The influence of Digges's treatise on contemporary astronomical thought can hardly be overestimated. The book in which it appeared was, as already indicated, one of the most popular works of the period. There are extant no less than seven editions containing Digges's *Perfit Description of the Caelestiall Orbes,* dated 1576, 1578, 1583, 1585, 1592, 1596, and 1605. For each edition the volume was completely reprinted; there are no cases of the reissue of old sheets with a new title-page. There may well have been several other editions of which no copy has survived. In Digges's book the average Englishman, who lacked the opportunity or the learning to read and understand Copernicus' great work in the original, got his first authoritative exposition of the new heliocentric theory and the arguments in its favor. Digges's reputation as one of

[12] *A Perfit Description of the Caelestiall Orbes,* sigs. N3^{v}-N4^{r}.

[13] According to the traditional figures of Alfraganus, the first-magnitude stars were only slightly smaller than the sun, being 107 times the size of the earth, as against 166 in the case of the sun.

the leading mathematicians and scientists in England lent added weight to his support of the Copernican system. The manner in which he set forth his idea of the infinite universe, moreover, apparently led the majority of his countrymen to believe that the notion that the fixed stars were located at varying distances throughout infinite space was an integral part of the heliocentric hypothesis.[14]

The close association, in the English mind, of the new Copernican system and the conception of the infinity of the universe has usually been attributed to the influence of Giordano Bruno. Bruno was in England from 1583 to 1585, and the first works in which he published his speculations concerning the infinite universe were printed in England during that period. These books, however, were written in Italian, and Bruno himself spoke no English. During his sojourn in England he seems to have been known only to a limited circle, and references to his cosmological speculations in English books do not begin to appear until several years afterward.[15] Then they are based upon his later Latin works printed abroad, rather than on his Italian works printed in London.

It was Digges's treatise proclaiming the idea of an infinite universe in conjunction with the Copernican system, and not Bruno's speculations on this subject, that influenced the thought of sixteenth-century England. Digges, moreover, was an eminent scientist, and was eager to verify his ideas by experimental methods. Bruno, on the other hand, had arrived at his notions entirely through metaphysical speculations;[16] the Copernican theory was seized upon and incorporated in his philosophy merely because it could be made to give seeming proof, in the physical realm, of ideas already arrived at by methods in which mathematical science played no part. It is entirely possible that Digges's brief treatise on the Copernican system first suggested

[14] See Johnson and Larkey, "Thomas Digges," pp. 115-16.

[15] See Oliver Elton, "Giordano Bruno in England," *Modern Studies* (London, 1907), pp. 1-36.

[16] Cf. the recently published work by A. O. Lovejoy, *The Great Chain of Being* (Cambridge, Mass., 1936), pp. 116-21.

to Bruno's mind the thought of using the new heliocentric theory as a physical proof of his highly speculative notions concerning the infinity of the material world. The *Perfit Description of the Caelestiall Orbes* had passed through at least two editions before Bruno's arrival in England and was reprinted twice during his sojourn there, so that he had ample opportunity to know of the work and may even have met Digges himself. Edward Dyer, the friend and patron of Dee and Digges, was also a member of the Sidney–Fulke-Greville group, the circle Bruno knew in England. If a definite intermediary were to be suggested, Dyer would be the most probable person.[17]

Digges's insistence, in his *Alae seu Scalae Mathematicae,* upon the need for experimental observations as a basis for determining the true structure of the universe by scientific methods, and his unwillingness to rest content with the purely metaphysical speculations of both ancient and modern philosophers, had great influence in guiding the course of English science for the next few decades. His writings directed attention to the problems raised by the conflicting cosmologies and pointed out the proper approach for investigators who desired to make some effort toward their solution. Digges gave no sanction to the tendency to fall back upon the traditional evasion of the moralists and the theologians: that such matters were improper subjects for human inquiry because it was sinfully presumptuous to attempt to discover the closely guarded secrets of the Deity.

The part that skilled artisans must play in designing and constructing new instruments and in improving various technical processes in order that further progress might be made in experimental science was fully realized by Thomas Digges, as it was by most of the leading English scientists of the sixteenth century. The translations of important scientific books and the

[17] Edward Dyer had also served with Thomas Digges on the committee appointed by the Privy Council in 1581 to report on the plans for the repair of Dover harbor. See the notice, under the date of June 14, 1581, in *Acts of the Privy Council of England,* New Ser., XIII (1896), 80. Richard Hakluyt the elder was another member of this committee.

writing, in English, of sound and scholarly treatises setting forth the fundamental principles of the mathematical sciences and their many applications to practical works were parts of a patriotic program for the advancement of English science. Digges makes this motive clear in many places. His *Pantometria* was designed to teach the application of correct geometrical methods to difficult problems in surveying and all types of mensuration, and his *Stratioticos* showed the application of similar methods to military fortification and ballistics. In the dedication of the latter work to the Earl of Leicester, Digges speaks of himself as "having spent many of my yeares in reducing the Sciences *Mathematicall,* from *Demonstratiue Contemplations,* to *Experimentall Actions,* for the seruice of my *Prince* and *Countrey.*" [18]

In the second edition of the *Pantometria* (1591), Digges, speaking of another work of his then in preparation, publicly renounced further publication in Latin, saying:

> And although by publishing the same my Treatize of Martiall Pyrotechnie and great Artillery in the Latin toong, I should I knowe greatlye amplifie myne owne Fame, and the admiration of such rare Mathematicians as this daye liue in seuerall Nations of Christendome, from whome I haue for farre inferior Inuentions Imprinted in my Treatize, Intituled *Alae seu scalae Mathematicae,* already receiued no small applause. Yet if I publish the same at all, I doe constantly resolue to doe it onely in my Natiue Language.[19]

Dee, likewise, states that the chief reason for the translation of Euclid into English was to make the whole science of geometry available to those without university training or skill in the Latin tongue, in order that they might put this knowledge to practical uses for their own good and that of the commonwealth. By the help of Euclid in their native language many students who otherwise would neglect scientific pursuits might become interested in them, and be inspired to

[18] *An Arithmeticall Militare Treatise, named Stratioticos* (London: H. Bynneman, 1579), sig. A2r.

[19] P. 176.

continue them, to the ultimate profit of mankind. He goes on to say:

> Besides this, how many a Common Artificer, is there, in these Realmes of England and Ireland, that dealeth with Numbers, Rule, & Cumpasse: Who, with their owne Skill and experience, already had, will be hable (by these good helpes and informations) to finde out, and deuise, new workes, straunge Engines, and Instrumentes: for sundry purposes in the Common Wealth? or for priuate pleasure? and for the better maintayning of their owne estate? [20]

Many important English scientific writers of the period were men lacking a university education, who, because of the helps which scholars like Recorde, Dee, and Digges provided for them, were able to bring sound mathematical principles to the aid of their practical experience and knowledge and thus make genuine contributions and discoveries. Such men were William Bourne, the writer of many able and popular books on navigation; Robert Norman, who, in his book *The New Attractive,*[21] first demonstrated the dip of the magnetic needle; William Borough, comptroller of Queen Elizabeth's navy and the author of a valuable book, *A Discours of the Variation of the Cumpas;* [22] and John Blagrave, the most famous designer of astronomical instruments in Elizabethan England. All of these self-educated scientists were greatly respected by men like Dee and Recorde for their genuine knowledge and achievements. Robert Norman presents with admirable directness the merited importance of the "Mechanicians" in the development of scientific learning:

> But I doe verilie thinke, that notwithstanding the learned in those sciences, beeing in their studies amongst their bookes, can imagine great matters, and set downe their farre fetcht conceits, in faire shew, and with plausible wordes, wishing that all Mechanicians, were such as for want of vtterance should be forced to deliuer vnto them their knowledge and conceits, that they might flourish vppon them, & applie them

[20] Preface to Euclid, sig. A4[r].

[21] London: for R. Ballard, 1581. There were many later editions.

[22] London: for R. Ballard, 1581. The treatise was usually appended to Robert Norman's *New Attractive.*

at their pleasures: yet there are in this land diuerse Mechanicians, that in their seuerall faculties and professions, haue the vse of those arts at their fingers ends, and can applie them to their seuerall purposes, as effectuallie, and more readilie, then those that would most condemne thē. For albeit they haue not the vse of the Greeke and Latine tongues, to search the varietie of authors in those artes, yet haue they in English for Geometrie, *Euclides* Elements, with absolute demonstrations: and for Arithmetike, *Records* workes, both his first and second part: and diuerse others, both in English, & in other vulgar languages, that haue also written of them, which bookes are sufficient to yᵉ industrious Mechanician, to make him perfect and readie in those sciences, but especiallie to apply the same to the art or facultie which he chieflie professeth. And therefore I would wish the learned to vse modestie in publishing their conceits, & not disdainfullie to condemne men that will search out the secrets of their artes and professions, and publish the same to the behoofe & vse of others, no more then they would that others shuld iudge of them, for promising much and performing little or nothing at al. *Aristotle* sayth, that euerie man is best to be beleeued in his owne professed Art and Science. Now (curteous reader) I am to request thee to accept of this my discourse, wherein I haue taken some paines (as the trauaile it selfe may testifie) and bene at some charge, for the more carefull and orderlie handling of such matters as are necessarilie incident to this present treatise: All which I haue bene content to doe, that the worke (though it be not big, yet effectuall) by the common vse thereof, may yeeld profit accordingly, to them specially that are of capacitie to comprehend this new reuealed secret. To conclude, the chiefest & onely marke whereat I lay leuell, was the benefiting of my Countriemen, in whom I wish continuall increase of knowledge and cunning, as in all other commendable professions, so chieflie in those that are most necessarie and profitable.[23]

In addition to explaining his discovery of the dip of the magnetic needle, Norman, in his *New Attractive,*[24] discussed briefly the variations of the compass, showing that the actual observations of mariners proved that this variation was not uniform, as had been maintained by earlier writers, including Martin Cortes. William Borough, to whom Norman presented his book, penned his *Discours of the Variation of the Cumpas* to "be annexed to" *The New Attractive,* and the two works are usually found together in the same volume. Borough's

[23] *The New Attractive* (1585 ed.), sigs. A3ᵛ-A4ᵛ.
[24] Chap. 9.

treatise gives detailed instructions for the accurate mathematical determination of the variation, and records observations of his own, made on his northeastern voyages, which clearly disproved the theory that the compass needle always pointed to a certain magnetic pole. Borough often refers his readers to Copernicus' *De revolutionibus* for the demonstration of certain mathematical propositions. His preface "To the Trauelers, Seamen, and Mariners of Englande" made a plea for the collection of accurate data on the variation of the compass in different parts of the world, so that the maps and sailing charts could be improved. Profound learning, according to Borough, was not essential for this task, because there were books in the English tongue "sufficient for an industrious and willyng minde to attain to greate perfection" in the necessary sciences of arithmetic, geometry, and astronomy.[25]

The practical and experimental nature of English science in the late sixteenth century cannot be too strongly emphasized, in view of the popular misconception of its character, derived largely from Bacon's highly misleading portrayal of the aims and methods of the scientists of his day.[26] The leading scholars, such as Digges and Dee, were not interested in mere abstract theory, except in so far as it was necessary for determining fundamental principles. Like Bacon, they had a clear vision of the practical utility of science for the relief of man's estate, and they sought the co-operation of all classes of workers in the realization of their dream, well aware of the potential value of each man's specialized experience and technique when intelligently applied to some designated end.

In astronomical research the influence of this experimental attitude, which owed so much to the work of Thomas Digges, persisted throughout the period we are studying, although some time elapsed before we have any recorded instances of definite results. The hope which Digges had held in 1573 that the new star would afford experimental proof of the truth of

[25] Sigs. *2r-*4r.

[26] For Bacon's comments on the state of science, see particularly the first book of the *Novum Organum, passim.*

the Copernican system was doomed to disappointment. Although astronomers had the opportunity of observing it for over a year and a half, they were unable to detect any annual parallax for this most famous super-nova. The old dilemma consequently remained to be faced by all the sixteenth-century scientists: either they must accept the hypothesis that there was an incredibly great interval of apparently empty space between the orbit of Saturn and the nearest of the fixed stars, together with the corollary that every one of the visible stars must be many times larger than the sun; or they must reject the main features of the Copernican theory and return to Ptolemy's cosmology or some less radical modification thereof. Digges's treatise of 1576 on the Copernican system proved that, in spite of the failure of the new star to furnish experimental verification of the heliocentric theory, he was not only willing to choose the former alternative, but also ready to go the full length in that direction and proclaim the stellar regions to be infinite. In view of his consistent advocacy of the experimental method, one naturally wonders what reasons prompted Digges to take this course. His known descriptions of an early type of telescope instantly come to mind in this connection, together with the descriptive title he gave in 1579 for a commentary on Copernicus which he had started to write. Among the " Bookes Begon by the Author, heereafter to be published " which he lists at the time was

Commentaries vpon the *Reuolutions* of *Copernicus,* by euidente Demonstrations grounded vpon late *Obseruations,* to ratifye and confirme hys *Theorikes* and *Hypothesis,* wherein also Demonstratiuelie shall be discussed, whether it bee possible vpon the vulgare *Thesis* of the Earthes *Stabilitie,* to delyuer any true *Theorike* voyde of such irregular Motions, and other absurdities, as repugne the whole *Principles* of *Philosophie* naturall, and apparant groundes of common *Reason.*[27]

What these " late *Obseruations* " were we can only conjecture, for Digges's treatise was probably never completed. The possibility that he had examined the heavens through a com-

[27] *Stratioticos,* sig. a4[r].

bination of lenses and mirrors corresponding to our modern telescope cannot be ruled out, although definite proof may never be forthcoming.[28] Even the most casual observation of the sky with such an instrument would have provided Digges with ample experimental justification for his assertion that the stellar regions should be conceived of as infinite. His observations would have revealed to him the fact that the stars are infinitely more numerous than they seem to the naked eye. At the same time, he would have discovered that his instrument, in giving clearer definition to the stars, did not increase their apparent diameters but showed them as mere points of light. The incredible sizes of the stars as compared with our sun—a difficulty that had been one of the chief scientific objections to the Copernican theory so long as these stars were assigned diameters of from one to two minutes of arc—would no longer have to follow as an inevitable consequence of the new system, so that this very powerful argument of its opponents would have been overcome.

There are many references in Digges's works to the marvels achieved in terrestrial observations by means of frames of lenses and mirrors, or "perspective glasses," to use the customary Elizabethan term for them. The most detailed description occurs at the end of Chapter 21 of the first book of his *Pantometria:*

> Thus much I thought good to open concerning the effects of a plaine Glasse, very pleasant to practise, yea most exactly seruing for the description of a plaine champion countrey. But marueilous are the conclusions that may be performed by glasses concaue and conuex of Circulare and parabolicall formes, vsing for multiplication of beames sometime the aide of Glasses transparent, which by fraction should vnite or dissipate the images or figures presented by the reflection of other. By these kinde of Glasses or rather frames of them, placed in due Angles, yee may not onely set out the proportion of an whole region, yea represent before your eye the liuely image of euery Towne, Village, &c. and that in as

[28] The numerous letters of Digges preserved in the Public Record Office, the British Museum, and elsewhere might yield some passing allusion which would point to the use of a telescope for stellar observations, but I have not as yet been able to make a thorough examination of these manuscripts.

little or great space or place as ye will prescribe, but also augment and dilate any parcell thereof, so that whereas at the first apparance an whole Towne shall present it selfe so small and compact together that yee shall not discerne anye difference of streates, yee may by application of Glasses in due proportion cause any peculiare house, or roume thereof dilate and shew it selfe in as ample forme as the whole towne first appeared, so that ye shall discerne any trifle, or reade any letter lying there open, especially if the sunne beames may come vnto it, as plainely as if you were corporally present, although it be distante from you as farre as eye can discrie: But of these conclusions I minde not here more to intreate, hauing at large in a volume by it selfe opened the miraculous effects of perspectiue glasses.[29]

The separate volume on perspective glasses, mentioned here, has apparently been lost. Among Digges's contemporaries, however, there was a keen interest in the properties of these combinations of lenses and mirrors, and numerous references were made to their use in terrestrial observations. Dee, for example, alludes to them several times in his preface to Euclid,[30] and doubtless dealt with them at some length in several of his unpublished manuscript treatises.[31] About 1580 William Bourne, one of the ablest practical scientists of the period, wrote at Lord Burghley's request a short treatise on the properties and qualities of glasses for optical purposes, and the

[29] Quoted from a copy of the second edition (1591) in the Huntington Library. The passage is identical in the first edition of 1571, except for the usual variations in spelling and punctuation due to the Elizabethan compositor. Other important references to perspective glasses in Digges's works are to be found in the preface to the *Pantometria* and also in the *Stratioticos*. The latter has been quoted above, p. 80. These references have been reprinted, with some omissions, by R. T. Gunther in *Early Science in Oxford,* II (Oxford, 1923), 288-93. Dr. Gunther also reprints extracts from William Bourne's treatise, discussed below, pp. 177-78. For a general account of the early history of the telescope, see Charles Singer, "Steps Leading to the Invention of the First Optical Apparatus," *Studies in the History and Method of Science,* II (Oxford, 1921), 385-413. In view of the many references in English works to the optical experiments of Leonard and Thomas Digges, and also to those of John Dee and William Bourne, I do not feel that Dr. Singer has given sufficient credit to the English group.

[30] Sigs. b1^{r}-b1^{v}, A1^{v}, A3^{v}.

[31] See the list Dee gives of his works in manuscript, in his "Compendious Rehearsall" (Chetham Society reprint, pp. 24-27). Note especially Nos. 6, 23, 24.

making, polishing, and grinding of them.[32] After discussing the method of manufacture and the properties of convex and concave mirrors and convex lenses, Bourne says, at the end of his treatise:

For that the habillity of my purse ys not able for to reache, or beare the charges, for to seeke thorowly what may bee done with these two sortes of Glasses, that ys to say, the hollowe or concave glasse: and allso that glasse, that ys grounde and polysshed rounde, and thickest on the myddle, and thynnest towardes the sydes or edges, Therefore I can say the lesse vnto the matter. For that there ys dyvers in this Lande, that can say and dothe know muche more, in thes causes, then I: and specially Mr. Dee, and allso Mr. Thomas Digges, for that by theyre Learninge, they have reade and seene many moo auctors in those causes: And allso, theyre ability ys suche, that they may the better mayntayne the charges: And also they have more leysure and better tyme to practyze those matters, which ys not possible for mee, for to knowe in a nombre of causes, that thinge that they doo knowe. But notwithstanding upon the smalle proofe and experyence those that bee but vnto small purpose, of the skylles and knowlledge of these causes, yet I am assured that the glasse that ys grounde, beynge of very cleare stuffe, and of a good largenes, and placed so, that the beame dothe come thorowe, and so reseaved into a very large concave lookinge glasse, That yt will shewe the thinge of a marvellous largeness, in a manner vncredable to bee beleeved of the common people. Wherefore yt ys to bee supposed, and allso, I am of that opinyon, that havinge dyvers, and sondry sortes of these concave lookinge glasses, made of a great largeness, That suche the beame, or forme and facyon of any thinge beeynge of greate distance, from the place, and so reseaved fyrste into one glasse: and so the beame reseaved into another of these concave glasses: and so reseaved from one glasse into another, beeynge so placed at suche a distance, that every glasse dothe make his largest beame. And so yt ys possible, that yt may bee helpped and furdered the one glasse with the other, as the concave lookinge glasse with the other grounde and polysshed glasse. That yt ys lykely yt ys true to see a smalle thinge, of very greate distance. For that the one glasse dothe rayse and enlarge, the beame of the other so wonderfully. So that those things that Mr. Thomas Digges hathe written that his father hathe done, may bee accomplisshed very well, withowte any dowbte of the matter: But that

[32] Before this, in his *Inuentions or Deuises* (London: Thomas Woodcock, 1578), Bourne had described the arrangement and use of lenses and mirrors for magnifying distant objects. See his 107th and 110th devices.

the greatest impediment ys, that yow can not beholde, and see, but the smaller quantity at a tyme.[33]

Another evidence of the familiarity of the sixteenth-century English scientists with some form of an early telescope and their use of it in terrestrial observations is found in Thomas Harriot's account of the instruments taken on the expedition to Virginia in 1585. Among others, he mentions " a perspectiue glasse whereby was shewed manie strange sightes." [34] Yet, despite the many proofs of the existence of optical instruments quite similar to the telescope, and the references, such as William Bourne's, to Dee and Digges as the two men most skilled in these matters, there is no clear proof that Digges or any other astronomer in England used a telescope for examining the heavens prior to the year 1609.[35] The earlier telescopes described by Digges, Dee, and Bourne seem to have been merely set up in frames, since there is no mention of an inclosing tube. But this fact would have no effect, of course, upon the evidence that would have been derived had Digges used his instrument for examining the heavens.

It seems most improbable that the idea of turning one of his frames of perspective glasses toward the sky would never have occurred to Digges during the course of his experiments. Both Digges and Dee refer to manuscripts of Roger Bacon as the principal sources of their knowledge concerning the properties of lenses and mirrors, and Bacon, in the passage describing the uses of combinations of these glasses for making distant objects appear large and close at hand, says that by their means

[33] MS Lansdowne 121 (reprinted by J. O. Halliwell in *Rara Mathematica* [London, 1841], pp. 32-47; the passage quoted is taken from this reprint, pp. 45-47).

[34] *A brief and true report of the new found land of Virgina* (London, 1588), sig. E4[r].

[35] In that year, as we shall see in Chapter VII, Thomas Harriot and his friends and pupils were using telescopes for astronomical observations prior to Galileo. These telescopes were of Harriot's own manufacture, with the assistance of his servant and mechanic, Christopher Tooke. They had apparently been developed independently in England, and been in use for some time prior to the first reference to them in the Harriot correspondence.

one could make the sun, moon, and stars apparently descend here below.[36] It is unlikely that Digges would have failed to follow up this suggestion if he had had the opportunity.

After about 1580, however, Digges had little chance to pursue consistently any series of astronomical or scientific investigations. Because of his ability as a military engineer he was called into the service of his country, first to supervise the fortification of Dover harbor, and later as muster-master-general of the English forces in the Netherlands. He thus had little time to devote to scientific research and writing, and none of the works he had under way in 1579 was ever completed and published. Furthermore, the lawsuits lodged by Digges against the cousin who had acted as his father's executor, in order to recover the sums this relative had embezzled, dragged on unsuccessfully through many years.[37] Digges never had the funds, therefore, to carry on the systematic astronomical research which he had proclaimed in the *Alae* as so necessary for the advancement of that science. His own fortune would not permit him to establish an observatory and equip it with instruments and a staff of trained assistants. The munificence of King Frederick II in handsomely endowing Tycho Brahe's work [38] deserves as great a share of the credit for the latter's splendid achievements as does Tycho's own genius. Digges never had any prospect of such a grant, for Elizabeth's finances were always in too precarious a state for her to give any thought to subsidizing astronomical research. After 1583, even the instruments and laboratories of his friend Dee were no longer available for Digges's use, because they had been destroyed by the mob that sacked Dee's house at Mortlake in the fall of that year.[39]

The influence of Thomas Digges's work on astronomical thought in England persisted for several decades, despite the

[36] *Opus Majus,* Pt. 5. See R. B. Burke's translation, *The Opus Majus of Roger Bacon* (Philadelphia, 1928), II, 582.

[37] Note the references to the "law-brables" at the end of the *Stratioticos,* in MS Lansdowne 67 (5), and in Hist. MSS Com., *Hatfield MSS,* IV, 396-99.

[38] See J. L. E. Dreyer, *Tycho Brahe* (Edinburgh, 1890), pp. 85-87.

[39] "Compendious Rehearsall," pp. 27-31.

fact that circumstances prevented his carrying through the program of scientific research he had envisioned. He had made a knowledge of the essentials of the Copernican theory available to all his countrymen and had implanted in their minds the notion that the infinity of the universe was an integral part of the heliocentric hypothesis. He had likewise done much to further the spirit of experimental research in England, and to direct the attention of English scientists to the possibility of solving the disputed points of cosmology by means of observations based upon scientific methods. Not only had he created an interest in the technical problems connected with fashioning those combinations of lenses and mirrors out of which the telescope in its modern form was to be evolved, but he had also led his countrymen to be on the alert for new discoveries which would afford satisfactory physical reasons for the planetary motions. He had contributed his share to exploding the physical theories of Aristotle which had been offered as explanation and proof of the earth's immobility in the center of the universe. As yet, however, no scientific physical reasons had been presented to explain what caused the earth to move in the way Copernicus supposed.

An Englishman and contemporary of Digges, William Gilbert, was the first to propose a physical explanation of the earth's rotation, ascribing it to the earth's magnetic properties. Although Gilbert's experiments were begun many years earlier, his great work, the *De Magnete*, was not published until 1600, five years after Digges's death. Before considering Gilbert's book, therefore, some account should be given of the progress of astronomy in England between the time of the publication of Digges's treatise in 1576 and the end of the sixteenth century.

From 1576 onwards, references to Copernicus become much more frequent in English books. Before this date the only important notices of the new system were confined to the works of the most eminent mathematical scientists. Thereafter, nearly every writer on astronomy felt it necessary to pay some attention to the heliocentric theory, if only to try to refute it by the con-

ventional Aristotelian arguments. The abler compilers of popular handbooks on that science usually adopted many of Copernicus' figures, particularly those for the precession of the equinoxes, and gave due praise to his astronomical skill regardless of whether they accepted the physical reality of his system. Incidental allusions in other types of books testify to the growing knowledge of the Copernican theory among many classes of English authors.

The new cosmological ideas were not being ignored in the universities. In 1576, the very year of Thomas Digges's treatise on the Copernican system, one of the questions assigned for disputation in Vesperies by candidates incepting as Masters of Arts at Oxford was, "An terra quiescat in medio mundi?"[40] Which side of the question was taken by the candidate and which by the proctor who responded is not indicated by the records, but we may be certain that the theories of Copernicus and the opposing doctrines of Aristotle were the chief subjects of debate. Among the questions in 1581 was, "An materia sit in caelo?" It indicates that the recent astronomical discoveries concerning the nature and location of comets and of the new star were having their repercussions in academic circles. A question argued in 1588 was, "An sint plures mundi?" The selection of such topics is evidence that the fundamental postulates of Aristotelian cosmology were regarded as live subjects for scholastic debate, regardless of which side the candidates were expected to take on the issues.

A mere enumeration of casual references to Copernicus in English books after 1576 would serve no useful purpose, but a few typical ones may be given here as indicative of the increasing knowledge of his work, and of the various attitudes toward it prevailing in England. Gabriel Harvey, in his poem in memory of Sir Thomas Smith written in 1578, mentions Copernicus and Rheticus in his summary of the world's greatest writers on astronomy, speaking of them in the following terms:

[40] *Register of the University of Oxford,* II, ed. Andrew Clark, Pt. 1 (Oxford, 1887), p. 170. The procedure at inception is described in the same volume, pp. 82-88.

. . . . . aliosqúe recentes
Astronomos, praeterqúe alios Copernicum acutum,
Praeconemqúe eius Ioachimum Rheticum . . .[41]

The passing allusion to the new astronomy in Sir John Davies' *Orchestra or A Poeme of Dauncing*[42] is notable for its favorable attitude toward the scientific basis for the idea of the earth's motion:

Onely the Earth doth stand for euer still,
Her rocks remoue not, nor her mountaines meete,
(Although some witts enricht with Learnings skill
Say heau'n stands firme, & that the Earth doth fleete
And swiftly turneth vnderneath their feete)
Yet though the Earth is euer stedfast seene,
On her broad breast hath Dauncing euer beene.[43]

Allusions to the new astronomy occur with increasing frequency in popular handbooks on scientific subjects, although most books of this type, it is true, continued for many years to reprint little more than epitomes of the conventional ideas. Francis Shakelton, in a book describing the comet of 1580 and the evils it foretold to the individuals and nations who refused to repent and amend their ways of life, refers to the fact that astronomers had proved that some comets, and the new star of 1572, were above the moon, where nature as typified by the four elements had no power. He mentions particularly, in this connection, Digges's book, the *Alae seu Scalae Mathematicae*.[44] In the philosophical encyclopedia written in French in 1575 by Louis Le Roy, and translated into English by Robert Ashley and published in 1594 with the title *Of the Interchangeable Course, or Variety of Things in the Whole World*,[45]

[41] *Musarum Lachrymae*, sig. F3v.

[42] London: J. Robarts for N. Ling, 1596. The book was entered in the Stationers' Register in 1594, so there may have been an earlier edition, no longer extant.

[43] Stanza 51, sig. B3v.

[44] *A blazyng Starre or burnyng Beacon* (London: J. Kyngston for H. Kirkham, 1580), sigs. D3r-D3v.

[45] London: C. Yetsweirt, 1594; fol. 126.

Copernicus is eulogized as one of the greatest of modern mathematicians, along with Regiomontanus, Peurbach, and Nicholas of Cusa.

Of even greater interest is a passage in a treatise on chemistry and medicine written by Richard Bostocke, entitled, *The difference betwene the auncient Phisicke . . . and the latter Phisicke.*[46] It proclaims the superiority of Paracelsian chemistry and medicine over the previous practice in those sciences. At the same time the author says, speaking of Paracelsus:

> He was not the author and inuentour of this arte as the followers of the Ethnickes phisicke doe imagine, as by the former writers may appeare, no more then *Wicklife, Luther, Oecolāpadius, Swinglius, Caluin, &c.* were the Author and inuentors of the Gospell and religion in Christes Church, when they restored it to his puritie, according to Gods word, . . . And no more then *Nicholaus Copernicus,* which liued at the time of this *Paracelsus,* and restored to vs the place of the starres according to the trueth, as experience & true obseruatiō doth teach is to be called the author and inuentor of the motions of the starres, which long before were taught by *Ptolomeus* Rules Astronomicall, and Tables for Motions and Places of the starres . . .[47]

Bostocke was obviously a Copernican. The same was not true of Thomas Hill, who compiled a popular textbook of astronomy. Yet Hill inserts many of Copernicus' figures and often refers to the heliocentric system, although he sides with the older theory and cites the usual Aristotelian reasons. Hill was probably the most prolific compiler of popular scientific handbooks during the third quarter of the sixteenth century. Little else is known about him, except that he must have died about 1575. Only two new works of his were published after that date. The first of these, if the pseudonym "Dydymus Mountaine" is meant to refer to the same Thomas Hill,[48] was entitled *The Gardeners Labyrinth.* This book was printed in 1577, and, in his dedication of the work to Lord Burghley, a

[46] London: R. Walley, 1585.

[47] Chap. 19; sigs. H7^{v}-H8^{r}.

[48] The obvious interpretation of this pseudonym is "Thomas Hill," and no other one seems plausible. Neither was there another person of that name writing scientific handbooks in England during this period.

certain Henry Dethicke states that he had been responsible for perfecting and publishing it after the author's recent death, because of a promise given his dying friend.[49]

The second work of Hill's to be published posthumously[50] was his treatise on astronomy, entitled *The Schoole of Skil.* This was not printed until 1599, when the deceased author's manuscript came into the hands of William Jaggard, who, realizing that the demand for works of this sort might make its publication a profitable venture,[51] saw it through the press and offered it for sale at his shop. Jaggard's preface, dated "April. 8. 1599," is of considerable significance as evidence of the general interest in scientific learning in England:

> Diuers haue writtē of sundry matters in former Ages, to the intent to benefit these our later times, wherin a man can name no kind of Art or Science, liberall or mechanicall, but there are as rare wits to bee found as euer liued since lerning florished. The reason is good that it should be so. For first, we haue come to our handes, vse and iudgement, whatsoeuer either antique or moderne Authors haue left behinde. Secondly, the gouernment (God be blessed) hath a long time (now these 40. yeares) bin so peaceable, that Students had neuer more libertie to looke into learning of any profession, for the inlarging of their vnderstanding. Lastly, the meanes otherwise, as well out of the vniuersities, as in them, haue been and are so many and so good, to attaine to all knowledge, that I dare be bold to say, *England* may compare with any Nation for number of lerned men, and for variety in professions. Of late a man of good merit, named *Tho. Hill,* painful with his pen whiles he liued, (as the world can witnesse, being possessed of sundry his works in Print) now deceased, left this Treatise Mathematical, intituled *The Rudiments of the Sphere*: which being found by iudgment of the lerned in the like profession, worthy the publishing, I haue, not only for the memory of the Author, but also for the profit of al wel affected Students, vndertaken to set forth. Therein whosoeuer bestoweth time & labor

[49] *The Gardeners Labyrinth* (London: H. Bynneman, 1577); other editions dated 1578, 1586, 1594, and 1608.

[50] *The Arte of vulgar arithmeticke* (1600), erroneously listed under Hill in the *Short-Title Catalogue*, was by Thomas Hylles, an entirely different person, as the dedication of that work clearly proves.

[51] A new edition of Recorde's *Castle of Knowledge* had been called for in 1596, while Blundeville's *Exercises* had been published in 1594 and again in 1597.

to read, with a temperate and sober spirit, I doubt not but they shall be satisfied in all such points, as this Mathematician pretendeth to handle.[52]

Hill's book has considerable merit as a textbook of the traditional astronomical ideas. Although it is mainly a compilation from the works of generally accepted authorities, without any attempt at a critical examination and sifting of their ideas, Hill has performed the compiler's task with commendable thoroughness. The many illustrative problems he gives are well designed for training the student in the practical applications of the science. In short, the book is definitely superior to Cuningham's *Cosmographical Glasse,* and the many references to Copernicus and the use of his figures [53] are indicative of the way in which the progress of the new astronomy among the ablest scholars was influencing the professional compilers of popular scientific handbooks. Hill's brief description and rejection of the Copernican theory is worth noting:

> *Aristarchus Samius,* which was 261 yeares, before the byrth of Christ, tooke the earth from the middle of the world, and placed it in a peculiar Orbe, included within *Marses* and *Venus* Sphere, and to bee drawne aboute by peculiar motions, about the Sunne, which hee fayned to stande in the myddle of the worlde as vnmoueable, after the manner of the fixed stars. The like argument doth that learned *Copernicus,* apply vnto his demonstrations. But ouerpassing such reasons, least by the newnesse of the arguments they may offend or trouble young students in the Art: wee therefore (by true knowledge of the wise) doe attribute the middle seate of the world to the earth, and appoynte it the Center of the whole, by which the risings, & settinges of the stars, the Equinoctials, the times of the increasing and decreasing of the dayes, the shadowes, and Eclipses are declared.[54]

The rapidly increasing knowledge of the new Copernican theory aroused the Aristotelians and the conservative theo-

[52] *The Schoole of Skil* (London: T. Judson for W. Jaggard, 1599), sigs. A3^{r}-A4^{r}.

[53] See p. 28, where Hill adopts Copernicus' figures for the size of the moon; p. 26, where the latter's figures for the sun are used; p. 19, where the calculations for the precession of the equinox are accepted.

[54] Pp. 42-43.

logians to renew their attacks upon it, even though its open supporters were still largely confined to the ranks of the mathematical scientists. Typical of the religious opposition to scientific ideas was the *Physica Christiana* of Lambert Daneau (1530-1596), a French Protestant divine, who spent many years teaching at Geneva. This book, published at Geneva in 1576, was devoted to a lengthy exposition of the thesis that all genuine scientific knowledge was to be sought in the passages of the Scriptures and not in the works of heathen philosophers like Plato and Aristotle. The book was translated into English by Thomas Twyne, and published in 1578 as *The Wonderfull Woorkmanship of the World.*[55] Daneau devotes many pages to a refutation of Plato's doctrine of "ideas," because "the Scripture in no place maketh mention of this *ideall* worlde, as they call it."[56] The doctrine of infinite worlds, held by Democritus and Epicurus, is also violently attacked.[57] Daneau is even uncertain as to whether the earth is spherical or not, since biblical passages can be quoted both for and against the idea. He finally concludes that God alone knows the truth, but that the probability is that the world is round.[58]

Another Frenchman, Guillaume Saluste Du Bartas, the author of one of the most famous poems of the Renaissance, was less narrow-minded in his attitude toward science. His poem, following the literary ideals of the time, was designed as a compendium of all knowledge and learning. *La Sepmaine, ou Création du monde*, first printed in complete form in Paris in 1578, gave a poetic description of the creation of the world. The poem was divided into seven parts, or "days," which parallel the account in Genesis of the order that the Lord followed in bringing the world and its creatures into being. Du Bartas' *La Seconde Sepmaine*, printed separately in 1584 and included with *La Sepmaine* in many later editions, was a collection of shorter poems dealing chiefly with supposed events in the early history of the world.

[55] London: Andrew Maunsell, 1578; quarto.
[56] Chaps. 10-12; fols. 23-28. [57] Fol. 26. [58] Fols. 28-29.

The popularity and influence of Du Bartas, and of Joshua Sylvester's English translation of his works, is recognized by all students of the literature of the English Renaissance and need not be discussed here. Sylvester's complete translation of the French poet was not published until 1605,[59] but many English editions of parts of Du Bartas had been printed before the end of the sixteenth century, and his poems were known in England from 1580 onwards. It is important, however, to realize that Du Bartas was a poet, not a scientist, and was lacking in any profound understanding of the underlying principles of astronomy or cosmology. His procedure was to take the ideas inherited from the late Middle Ages, as he found them set forth in the great encyclopedias of knowledge, and cast them in poetic form. He also borrowed freely from the ancient cosmological poets, such as Lucretius, but without any attempt to reduce to a consistent system the often conflicting theories which he embodied in his *Weekes*.[60] At the same time, he constantly sought to emphasize the moral and religious aspect of his material, and to make his work a sort of Christian epic. His "First Day of the First Week" opens with a bitter refutation of those "atheists" who held to Aristotle's idea that the world was eternal, without beginning or end, or who accepted Democritus' idea of infinite worlds.[61] His arguments here are the usual ones of the encyclopedists, derived, in turn, from the early Church Fathers. When he feels called upon to confute new ideas which disagree with his authorities, he makes little attempt to examine and to understand the reasons behind these theories, but scornfully rejects them simply because of their novelty. His method of refutation is based upon repeated assertions rather than upon any attempts at logical proof.

[59] *Bartas: His Deuine Weekes and workes Translated: . . . by Iosuah Sylvester* (London: Humfrey Lownes, 1605). There were numerous subsequent editions, issued throughout the seventeenth century.

[60] Cf. Virgil K. Whitaker, "Du Bartas' Use of Lucretius," *Studies in Philology*, XXXIII (Apr., 1936), 134-46.

[61] Ll. 38-95, 346-91, of Sylvester's translation. I have used A. B. Grosart's edition, *The Complete Works of Joshuah Sylvester* (Edinburgh, 1880).

This is exactly the method he follows in discussing the Copernican theory. He gives none of the arguments favoring the Copernican system, but merely recites a list of the Aristotelian physical axioms denying the earth's motion. These axioms, as we have already seen, were rapidly being disproved by the experimental scientists of Du Bartas' own day. It is significant, nevertheless, that Du Bartas does not brand the Copernicans as atheists, but merely holds them up to scorn for their wilfulness in denying Aristotle's doctrines of motion.

As the Ague-sick, upon his shivering pallet,
Delayes his health oft to delight his palat;
When wilfully his taste-less Taste delights
In things unsavory to sound appetites:
Even so, some brain-sicks live there now-adayes,
That lose themselves still in contrary wayes;
Prepostrous Wits that cannot row at ease,
On the Smooth Channell of our common Seas.
And such are those (in my conceit at least)
Those Clarks that think (think how absurd a jest)
That neither Heav'ns nor Stars do turne at all,
Nor dance about this great round Earthly Ball;
But th' Earth itself, this Massie Globe of ours,
Turns round-about once every twice-twelve hours:
And we resemble Land-bred Novices
New brought aboord to venture on the Seas;
Who, at first lanching from the shore, suppose
The ship stands still, and that the ground it goes.
So, twinkling Tapers, that Heav'n's Arches fill,
Equally distant should continue still.
So, never should an arrow, shot upright,
In the same place upon the shooter light;
But would doe (rather) as (at Sea) a stone
Aboord a Ship upward uprightly thrown;
Which not within-boord falls, but in the Flood
A-stern the Ship, if so the Winde be good.
So should the Fowls that take their nimble flight
From Western Marches towards *Morning's* light;
And *Zephyrus,* that in the Summer time
Delights to visit *Eurus* in his clime;
And bullets thundred from the canon's throat
(Whose roaring drowns the Heav'nly thunder's note)
Should seem recoil: sithens the quick career,

That our round Earth should dayly gallop here,
Must needs exceed a hundred-fold (for swift)
Birds, Bullets, Windes; their wings, their force, their drift.
Arm'd with these Reasons, 't were superfluous
T' assaile the Reasons of *Copernicus;*
Who, to salve better of the Stars th' appearance,
Unto the Earth a three-fold motion warrants:
Making the Sun the Center of this All,
Moon, Earth, and Water, in one onely Ball.
But sithence here, nor time, nor place doth sute,
His *Paradox* at length to prosecute;
I will proceed, grounding my next discourse
On the *Heav'n's motions,* and their constant *course.*[62]

Sylvester's translation, because of its popularity, helped to spread the knowledge of the Copernican theory, and may well have prompted the more curious readers to inquire further into the hypothesis which had been dismissed so summarily.[63] There were many Englishmen who, although willing to pay lip service to the idea, which Du Bartas and many others proclaimed, that man should not inquire too curiously into the mysteries of creation, were nevertheless eager to discover whatever they could concerning the true nature of the universe.[64]

Du Bartas' popular poem upheld the physical theories of Aristotle against the moderns who had the temerity to question them. At the time that his work was first published in France, however, the Ramist controversy was at its height in England, especially at the University of Cambridge. The protagonists in this dispute, so far as published books were concerned, were Everard Digby and William Temple; but

[62] "Fourth Day of the First Week," ll. 146-91.

[63] Du Bartas' poem, *The Columnes,* the fourth part of the second day of the second week, is a poetic description of the four liberal arts of the quadrivium: arithmetic, geometry, astronomy, and music. Astronomy is pictured with a celestial globe in one hand and a terrestrial globe in the other, and the author describes their use and also the use of the astrolabe. The descriptions are poetic, rather than precise and accurate, and indicate that Du Bartas was not an expert in such matters, although he gives an outward appearance of profound learning.

[64] George Buchanan's *De Sphaera,* first published in 1584, was another well-known poem of this period setting forth the old cosmology. It was less widely read than Du Bartas, however, because it was written in Latin.

the entire university was divided into two camps, with the uncompromising Aristotelians on one side and their Ramist opponents on the other. Digby, who became a fellow of St. John's College and began to give public lectures in logic in 1573, was the leading spirit in the academic revival of Aristotelianism in England. But, at the very time he began his teaching, the influence of Ramus' attack on the dialectics of Aristotle had already reached the stage where his books were being studied in place of the *Organon.* Remarks made by Gabriel Harvey in 1573 prove that Ramus' philosophy was already well known at Cambridge, and sufficiently esteemed to be quoted by Harvey in support of his own criticisms of Aristotle's ideas.[65] Harvey clearly belonged to the Ramist party in this controversy, and upheld the right to examine Aristotle's ideas and reject those that did not agree with reason.[66]

William Temple, though not so familiar to posterity as Harvey, was the chief controversial writer for the Ramist party during this period.[67] He matriculated at King's College in 1573, and later became a fellow of that college and taught logic in the university. He was secretary to Sir Philip Sidney from 1585 until the latter's death, and afterwards was secretary to the famous Earl of Essex. Temple's writings were mainly in support of Ramus' system of logic against the Aristotelians, but the French philosopher's writings on the mathematical sciences, of which we have spoken in the preceding chapter, also played an important role in this controversy. It was because Harvey was " a great and continual patron of paradoxis and a

[65] *Letter-Book of Gabriel Harvey,* ed. E. J. L. Scott (London: Camden Society, 1884), p. 10.

[66] Cf. his references to Ramus in the *Letter-Book,* pp. 10, 167, 181; also the many references in *Gabriel Harvey's Marginalia.*

[67] For further details concerning Digby, Temple, and the Ramus controversy at Cambridge, see J. B. Mullinger, *The University of Cambridge,* II (Cambridge, 1884), 404-15, and W. R. Sorley in the *Cambridge History of English Literature,* IV, 273-77. For a more comprehensive study of the philosophical writings of Digby and Temple, see J. Freudenthal, " Beiträge zur Geschichte der englischen Philosophie," *Archiv für Geschichte der Philosophie,* IV (1891), 450-77, 578-603, and V (1892), 1-41.

main defender of straung opinions, and that communly against Aristotle too," [68] that the fellows of Pembroke Hall attempted to oppose the granting of his M.A. in 1573. Harvey freely admitted the charge of defending against Aristotle such propositions as " Coelum non est quintae naturae," but quoted Ramus and others as modern authorities whose validity equaled the Greek philosopher's.

Nashe and Greene were of the opposing Aristotelian party, and it has been argued—quite rightly, I believe—that the animosity between the partisans of Ramus and of Aristotle at Cambridge during the eighties was one of the underlying causes of the ill-feeling of Greene and Nashe toward the Harveys.[69] Certainly, in the pamphlet warfare between Nashe and Harvey, one of the taunts which the former constantly hurls at the latter concerns Harvey's presumption in criticizing Aristotle, and his support of Ramus. Dr. McKerrow wisely remarks that behind the conflict between Harvey and Nashe was " that ancient opposition between the old and the new, between servility and independence. . . . And it was the Harveys who stood for the future and Nashe for the past." [70] In defending Harvey against the charges of his enemies, Dr. McKerrow says:

> The charge of maintaining paradoxes and strange opinions is one of the most honourable which can be brought against a scholar or a scientist. It is a charge which has been brought against every man who has contributed to the progress of the world, and never yet was a nonentity so accused.[71]

Harvey's eager curiosity in all matters pertaining to science, and particularly to astronomy, caused him to seek out the works and the company of the ablest scientists of his day. The list of men that Harvey cites in his writings and in his marginalia includes almost every important English scientific writer of the sixteenth century. He shows an acquaintance with the works

[68] *Letter-Book,* p. 10.

[69] Chauncey Sanders, *Robert Greene and the Harveys* (Indiana University Studies, XVIII [1931], No. 93), pp. 26-29.

[70] *The Works of Thomas Nashe,* V (London, 1910), p. 67.

[71] *Ibid.,* p. 70.

of most of these men, and must have had copies of their books in his own library, since many such volumes have survived that contain Harvey's autograph and annotations.[72] He also knew several of the leading scientists personally. It is certain that he numbered Thomas Digges and John Blagrave among his acquaintances,[73] and through them he may have met some of the other scientific writers whose achievements he praised so warmly, and with whose works he showed such an intelligent familiarity.

Like the scientists we have discussed, Harvey had the vision of the practical utility of scientific research and the realization of the significant part skilled artisans as well as learned scholars must play in this essentially co-operative enterprise. In *Pierces Supererogation* he writes:

> He that remembreth Humfrey Cole, a Mathematicall Mechaniciã, Matthew Baker a ship-wright, Iohn Shute an Architect, Robert Norman a Nauigatour, William Bourne a Gunner, Iohn Hester a Chimist, or any like cunning, and subtile Empirique, (Cole, Baker, Shute, Norman, Bourne, Hester, will be remembred, when greater Clarkes shalbe forgotten) is a prowd man, if he contemne expert artisans, or any sensible industrious Practitioner, howsoeuer Vnlectured in Schooles, or Vnlettered in Bookes. . . . and what profounde Mathematician, like Digges, Hariot, or Dee, esteemeth not the pregnant Mechanician? Let euery man in his degree enioy his due: and let the braue enginer, fine Daedalist, skilfull Neptunist, maruelous Vulcanist, and euery Mercuriall occupationer, that is, euery Master of his craft, and euery Doctour of his mystery, be respected according to the vttermost extent of his publique seruice, or priuate industry.[74]

[72] Harvey's own copies of works by Blagrave, Bourne, Hill, and Hood have survived, and contain his annotations. His marginalia contain references to Digges's *Prognostication euerlasting* (*Marginalia*, p. 175), to Recorde's arithmetic (p. 195), to Cuningham's *Cosmographical Glasse* (p. 213), and to Blundeville's works (p. 213). Harvey's printed books also contain many notices of English scientific works by Digges, Norman, and William Borough (see *The Works of Gabriel Harvey*, ed. A. B. Grosart [London, 1884-85], II, 97, 99).

[73] See *Marginalia*, p. 211, where Harvey mentions that Digges and Blagrave had personally recommended to him an excellent instrument maker, Mr. Kynvin. Harvey also knew of Digges's admiration for Palingenius and his habit of often repeating parts of the *Zodiacus vitae* from memory. See *Marginalia*, p. 161.

[74] *The Works of Gabriel Harvey*, ed. Grosart, II, 289-90. See also *Marginalia*, pp. 211-13.

The diversity of Harvey's scholarly interests, and the learned, if not pedantic, cast of his mind made him a particularly ardent supporter of the Renaissance conception of poetry as a learning. No one believed more strongly than he that the function of a great poem was to epitomize all important knowledge in both natural and moral philosophy. Harvey expressed this ideal in the notes he wrote on the flyleaf at the beginning of one of his volumes, wherein five small books, one of which had been given to him by his friend Edmund Spenser, were bound together.

Other commend Chawcer, & Lidgate for their witt, pleasant veine, varietie of poetical discourse, & all humanitie: I specially note their Astronomie, philosophie, & other parts of profound or cunning art. Wherein few of their time were more exactly learned. It is not sufficient for poets, to be superficial humanists: but they must be exquisite artists, & curious vniuersal schollers.[75]

As a "curious vniuersal scholler," Harvey fully lived up to the Renaissance ideal he expressed so succinctly; but he unfortunately was not endowed with any poetic genius. Though he himself lacked the art to make truly poetic use of recondite scientific knowledge, he took particular delight in poetry based upon sound learning. He especially admired the astronomical descriptions in Chaucer and Lydgate, and considered them "much better learned then owre moderne poets."[76] He pointedly complained of Spenser's comparative ignorance of astronomy, because he considered a mastery of that science essential to a great poet:

Pudet ipsum Spenserum, etsi Sphaerae, astrolabijque non planè ignarum; suae in astronomicis Canonibus, tabulis, instrumentisque imperitiae. Praesertim, ex quo vidit Blagraui nostri Margaritam Mathematicam. Qui né Pontano quidem, aut Palingenio, aut Buchanano, aut etiam Bartasio cedit, exquisita vtriusque Globi, astrolabij, baculique familiaris scientia. Vt alter iam Diggesius, vel Hariotus, vel etiam Deius videatur. Aureum calcar non rudium aemulorum.[77]

[75] *Marginalia,* pp. 160-61.
[76] *Ibid.,* pp. 159-60.
[77] *Ibid.,* pp. 162-63.

A rereading of the astronomical passages in Spenser's poems enforces the truth of Harvey's criticism. Spenser's knowledge of astronomy may seem very extensive to the modern reader, for the average educated person of today is often completely ignorant of even the elementary principles of the stellar motions, whereas his Elizabethan counterpart would at least have known as much as was contained in some simple textbook like Sacrobosco and would have been able to recognize the most important constellations in the heavens.

Beyond this minimum level of astronomical lore that was the common possession of all his educated contemporaries Spenser, apparently, never rose. He never acquired Chaucer's easy familiarity with the actual processes of astronomical observation and computation, which enabled the author of the *Canterbury Tales* to fix the season or the time of day by poetic, yet exact, references drawn from the science of astronomy.[78] It was this poetic use of material derived from the precise learning of the scholar and scientist that Harvey so greatly admired in Chaucer and earnestly wished to have Spenser imitate. An instance of the sort of careless handling of astronomical data that annoyed Harvey is found in the passage in Book I, Canto iii, of the *Faerie Queene,* where Una and her lion seek refuge for the night in the cottage of Abessa and Corceca. The poet indicates the passage of time during the night, and the arrival of an hour about midnight or somewhat later, by the lines:

> Now when *Aldeboran* was mounted hie
> Aboue the shynie *Cassiopeias* chaire,
> And all in deadly sleepe did drowned lie,
> One knocked at the dore, and in would fare; . . .[79]

It so happens that this situation of Aldebaran with respect to Cassiopeia during the midnight hours can only occur during the winter months, whereas the entire setting of the poem is in summertime.[80]

[78] Cf. Walter Clyde Curry, *Chaucer and the Mediaeval Sciences* (New York, 1926).

[79] Stanza 16.

[80] Aldebaran is high above Cassiopeia when the right ascension of the meridian

Here, however, is not the place to discuss Spenser's cosmological ideas, nor his use of astronomical material in his poetry. Certain it is that he did not, like his friend Gabriel Harvey, keep in close touch with the latest scientific investigations and theories in his own day. His poetry, although reflecting many of the currents of thought that inspired the new scientific movement, seems never to have been directly influenced by any of the events in its progress.[81]

Gabriel Harvey was only one among many English scholars whose interest in the mathematical sciences was doubtless strengthened as a result of the Ramus-inspired controversy between the old and the new learning, which raged at Cambridge while he was a member of the university. A number of other men who later contributed to the spread of mathematical and scientific knowledge were students at Cambridge during this period. The principal ones, including William Kempe, William Bedwell, and Thomas Hood, testified to the influence of Ramus and his books in arousing an interest in science by their references to him in their writings, and by their translations of Ramus' mathematical works into English.[82]

is between 5 and 6 hours. If this occurred between midnight and 2:00 A.M., the allowable limits for the right ascension of the sun would fall between 17 and 20 hours, making the time of year December or January.

[81] For example, there is no allusion to the new star of 1572, and its shattering of the Aristotelian doctrine of the changeless heavens, although in the "Mutabilitie" cantos Spenser's theme offered an appropriate occasion for such a reference.

[82] William Kempe (B.A., 1580; M.A., 1584) was the author of *The Education of children in learning* (London: T. Orwin, 1588), in which the teaching of mathematics was strongly advocated, and of a translation of Ramus' *Arithmeticae* entitled, *The Art of arithmeticke in Whole Numbers and Fractions* (London: R. Field for R. Dexter, 1592). William Bedwell (B.A., 1585; M.A., 1588), in addition to his books on mathematical instruments, translated Ramus' *Geometriae,* with additions and commentaries of his own. This book was published after his death, under the title *Via Regia ad Geometriam* (London: T. Cotes, sold by M. Sparke, 1636). Thomas Hood (B.A., 1578; M.A., 1581), besides his many works on the mathematical sciences, published an epitome of Ramus' *Geometriae* as *The Elementes of Geometrie* (London: J. Windet for T. Hood, 1590).

VITA

Francis Rarick Johnson was born at Otoe, Oklahoma, on August 14, 1901. He received his elementary and secondary education in the public schools and at Stadium High School, Tacoma, Washington. In 1919 he entered the United States Military Academy at West Point and graduated in 1923, ranking number one in the class. Upon graduation he was commissioned as a Second Lieutenant in the Corps of Engineers, United States Army, and was stationed first at the Engineer School, Fort Humphreys, Virginia, and later with the Sixth Engineers at Fort Lewis, Washington. Having been awarded a Rhodes Scholarship from the State of Washington, he entered Oxford University in 1925 and read for the Honours School of English Language and Literature. A mismanaged operation by the Army Medical Corps early in 1928 resulted in his retirement from active service with the rank of First Lieutenant in 1929. After he had had this faulty operation corrected, he returned to Oxford and completed the work which it had interrupted. In 1932 he received the Honours B. A. and M. A. degrees in English Language and Literature at Oxford University. From October, 1931, to March, 1932, and again during the year 1932-33, he was a graduate student in residence at the Johns Hopkins University. In 1933 he was appointed a Huntington Library International Research Fellow to study the history of scientific thought in England from 1500 to 1650, and he continued his research at the Huntington Library until April, 1935.